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- X. "On the Structure and Affinities of Fossil Plants from the Palæozoic Rocks.—On *Cheirostrobis*, a new Type of Fossil Cone from the Lower Carboniferous Strata (Calciferous Sandstone Series)." By Dr. D. H. SCOTT, F.R.S.

"The Production of X Rays of Different Penetrative Values."
By A. A. C. SWINTON. Communicated by LORD KELVIN,
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As is well known, if the X rays coming from an ordinary Crookes tube of the Jackson focus type be observed with a fluorescent screen during the process of exhaustion, the penetrative value of the rays is found to change as the exhaustion proceeds.

First of all, at less than a certain degree of vacuum, no X rays are produced. Next, as the vacuum is increased, X rays commence to show themselves, but of a quality that will do little more than penetrate the backing of the screen. As the vacuum is further increased, the rays become more penetrative, and show the shadow of the bones in the hand. As exhaustion proceeds further, a point is reached when the flesh of the hand seems to be almost completely transparent, while the bones are almost entirely opaque. At higher vacua than this, the bones becoming more and more transparent, the contrast between bones and flesh becomes less and less, till at length, at the very highest vacuum at which the discharge will pass, the bones scarcely show at all, owing to their having become nearly as transparent as the flesh, while the whole hand throws but a very faint shadow on the screen.

Similarly, it is found that, at any given degree of vacuum, the penetrative value of the X rays is increased by increasing the power

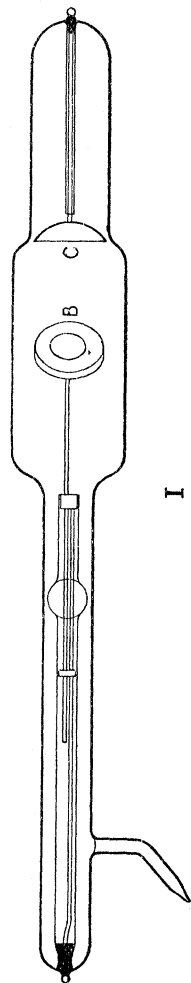
of the Ruhmkorff coil, and thereby increasing the difference of the electrical potential between the cathode and the anode portions of the tube, as measured by the length of the alternative spark in air.

Again, similar results are obtained without alteration to the vacuum or to the power of the Ruhmkorff coil by varying the resistance of the tube by means of a magnetic field.*

In this case the gradual strengthening of the magnetic field produces a gradual decrease in the resistance of the tube and of the difference of the electrical potential between the cathode and anode, and, at the same time, causes a gradual diminution of the penetrative value of the X rays.

I have further found that it is possible to vary the penetrative value of the X rays produced in a focus tube by simply altering the distance between the cathode and the anti-cathode.

For this experiment the tube, fig. 1, was constructed, in which the anti-cathode B of aluminium, faced with platinum, is connected to the anode terminal by a sliding steel rod, so that it could be moved along the axis of the tube, and the distance between cathode C and centre of the anti-cathode B varied from 1 to 3 inches, the anti-cathode being always outside the focus of the cathode. The tube was exhausted to a degree that gave a maximum contrast between the bones and flesh of the hand when the anti-cathode was midway between its two extreme positions, and was then sealed off, so that the vacuum was not varied during subsequent experiments. Upon the anti-cathode being approached to the cathode, the X rays immediately became of a more penetrative value, just as though the vacuum had been increased, while, at the same time, the potential difference, as measured by the alternative spark, was found to have risen. Again, when the anti-cathode was moved in the opposite direction and placed at a greater distance from the cathode, the potential difference fell, and the X rays became less penetrative and similar to those produced at a lower vacuum. In this way, without varying the vacuum, the pene-

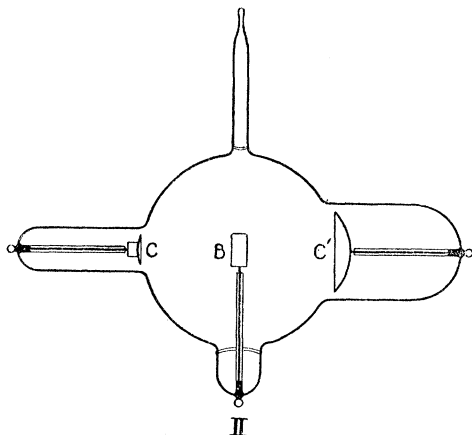


* See "The Effects of a Strong Magnetic Field upon Electric Discharges in *Vacuo*," 'Roy. Soc. Proc.' vol. 60, p. 179, and note in 'Nature' for July 9, 1896, p. 239.

trative value of the X rays could be increased or decreased as desired within the limits of the focus on the one hand and the travel of the anti-cathode on the other.

Again, I have found that the penetrative value of the X rays can be altered by employing cathodes of different diameters.

Having noticed that focus tubes with small cathodes give X rays of any given penetrative value at a much lower exhaustion than do exactly similar tubes having cathodes of larger diameter, the tube, fig. 2, was constructed, in which there are two cathodes, C and C',



both focussing upon opposite sides of the same platinum anti-cathode. B. The two cathodes were of dissimilar diameter, C being 0.375 in. diameter, and C' 1.125 in. diameter. Both had the same radius of curvature, namely, 0.75 in.

On exhausting this tube with the smaller cathode, C, in use, and the other not connected, a degree of vacuum was soon reached when X rays began to be produced plentifully. Pumping was then suspended, and the negative connection changed from the smaller cathode, C, to the larger, C'. Under these conditions, no X rays could be obtained, the vacuum being evidently much too low for the larger cathode. On continuing the exhaustion to the point when, with the larger cathode in operation, X rays were produced, but of a low penetrative value, the negative connection was removed from the larger cathode, and the smaller cathode put into use. Immediately it was found that the penetrative value of the X rays had increased to an extent that could only be obtained with the larger cathode with a very much higher vacuum.

Throughout the experiments with this tube it was further found

that the potential difference, as measured by the alternative spark in air, was much greater when the small cathode was in use than with the larger cathode.

The penetrative value of the X rays produced by any given tube appears, therefore, to be dependent upon several conditions.

1. The penetrative value is higher for a high vacuum than for a low vacuum.

2. It is higher when the electrical power applied is great than when it is small.

3. It is higher when the resistance of the tube is great than when this resistance is reduced by magnetic means.

4. It is higher when the distance between the cathode and anti-cathode is small than when the distance is great.

5. It is higher when the cathode itself is small than when it is large.

6. It is higher when, as a consequence of one or more of the above, the potential difference between the cathode and the anode portion of the tube, and consequently the electrical excitation of the cathode, is great than when it is small.

On the assumption that the cathode rays consist of negatively charged molecules that are repelled from the similarly electrified cathode with an initial velocity that depends upon the degree of electrical excitation of the cathode, the above conditions are those that would conduce to a high average velocity of the molecules at the moment at which they strike upon the anti-cathode, and, at the same time, to a high average difference of potential between the travelling molecules and the anti-cathode at the moment of impact.

At high exhaustions, not only is the electrical excitation more, and the initial velocity of the molecules consequently greater, but, owing to the smaller number of collisions with the other molecules of residual gas in the tube, the average velocity of the molecules and the amount of their negative charge have suffered less diminution by the time they reach the anti-cathode than in the case of lower exhaustions.

Similarly, when more electrical power is employed, the electrical excitation and the initial velocity of the molecules is increased, while the employment of a magnetic field reduces the resistance and the electrical excitation, and consequently reduces the initial velocity and negative charge of the molecules.

Again, when the anti-cathode is near to the cathode, the moving molecules having a less distance to travel before they reach the anti-cathode, have by that time lost less of their initial velocity and charge by collisions than when the anti-cathode and cathode are further apart.

And, lastly, not only does a small cathode become charged to a

higher electrical potential than a large one, and consequently impart a higher initial velocity and charge to the molecules, but with a small cathode the travelling molecules are more compactly arranged than with a large cathode, and consequently are not likely to make so many collisions and lose so much in velocity or electrical charge during their transit.

It would, therefore, appear that, whatever the precise cause, the penetrative value of the X rays produced under any given set of conditions is dependent upon the average velocity of the molecules and the difference of potential between them and the anti-cathode at the moment of impact, being higher the higher the velocity and the greater the potential difference.

Further, since the excitation of the cathode is not uniform, but varying, so that different molecules have different initial velocities and charges imparted to them, and since some of the molecules will make fewer collisions than others, and some molecules will thus strike the anti-cathode at higher velocities and in a more highly charged state than others, the same hypothesis will account for X rays being more or less heterogeneous under all conditions.

Finally, it appears that the penetrative value, as distinct from the quantity, of X rays is independent of the material of which the anti-cathode surface is made. Experiments with a tube in which the anti-cathode was made partly of platinum and partly of aluminium, and so arranged that by inclining the tube the anti-cathode could be moved, and either the platinum or the aluminium part could be brought into use, show that, even with metals having such very dissimilar atomic weights, the penetrative value of the X rays produced was the same, though the quantity of the rays as measured by photographic action or by the brightness of a screen of barium platino-cyanide was distinctly greater with the platinum. Further experiments with other tubes fitted with anti-cathodes of aluminium, iron, copper, silver, and platinum confirm these results. The metals of high atomic weight form the most efficient anti-cathodes, and give a larger quantity of X rays, though the difference is not so great as might, perhaps, be expected. All, however, appear to give X rays of the same penetrative value under similar conditions.

I am indebted to the assistance of Mr. J. C. M. Stanton and of Mr. H. L. Tyson Wolff for the exhaustion and manufacture of the various tubes with which the above experiments have been made.

